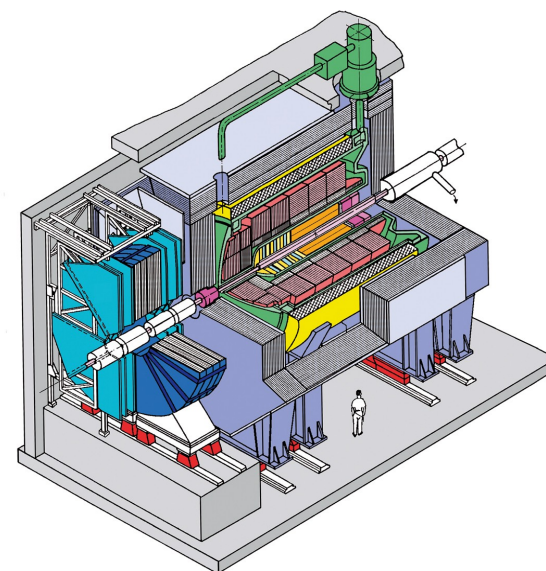


# Study of Charm Fragmentation Function at H1

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for H1 Collaboration

Fragmentation workshop, Trento  
25.-29. February 2008



- Introduction
- Observable definitions & measurement
- Extraction of fragmentation parameters

# Introduction

- ▶ Production cross-section for inclusive process  $ep \rightarrow H+X$ :

$$\sigma_H = \sum_i \sum_k f_{i/p}(x, \mu_f) \otimes \hat{\sigma}_{i\gamma \rightarrow kX}(\alpha_s(\mu_r), \mu_r, \mu_f) \otimes D_k^H(z, \mu_f)$$

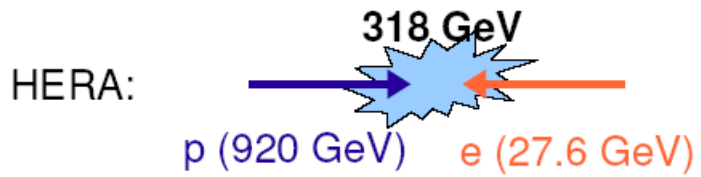
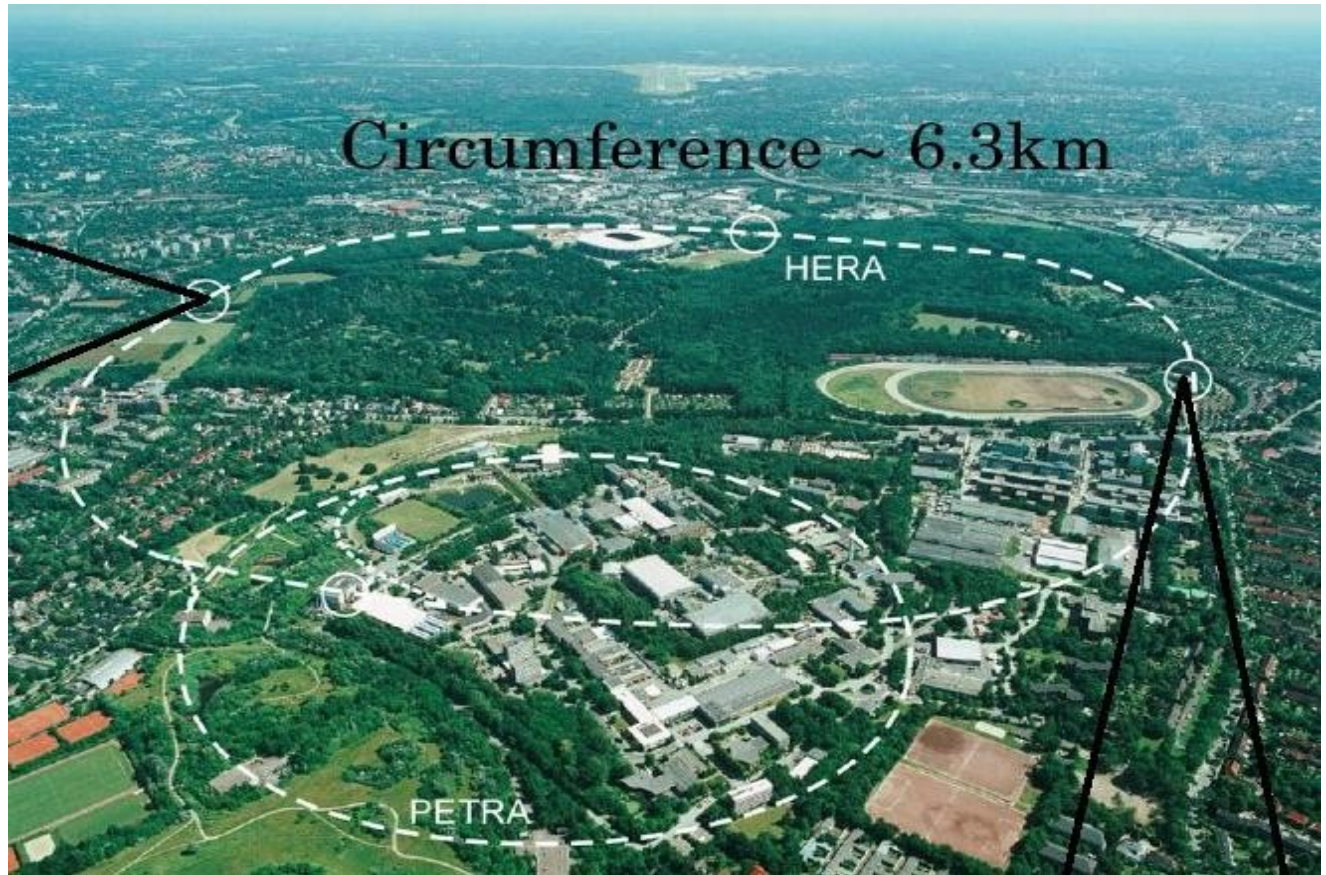
  
**Parton Density  
Function**

  
**Hard Scattering  
(perturbative)**

  
**Fragmentation  
Function**

- ▶ **Fragmentation functions FF:**
  - ▶ non-perturbative process ==> need to be experimentally studied
  - ▶ charm FF already precisely measured in  $e^+e^-$
  - ▶ with ep data we can check if universality holds

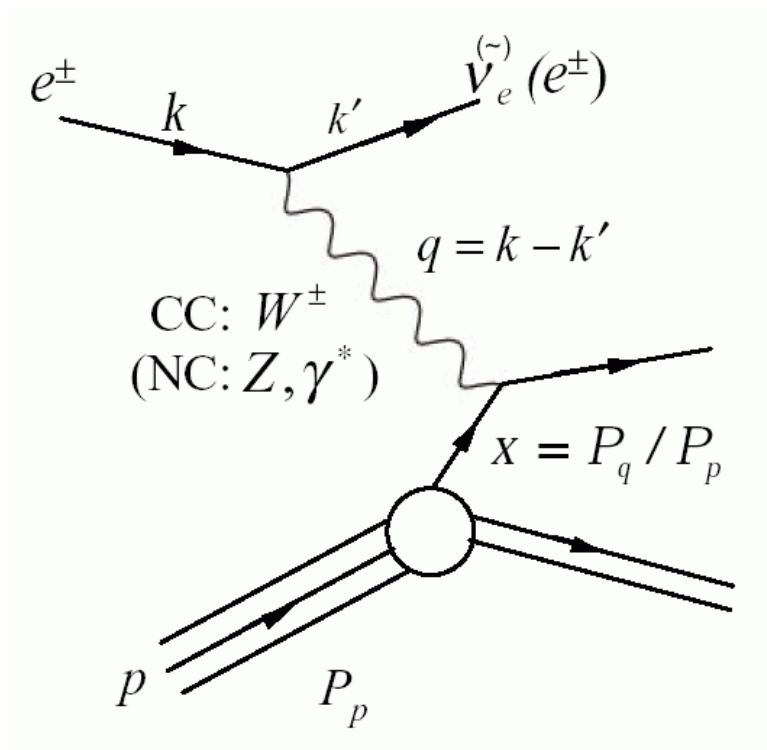
# H1 & HERA Collider



1999+2000 HERA I data:  
Luminosity  $\approx 47 \text{ pb}^{-1}$



# ep Event Kinematics



- ▶ **Four-momentum transfer:**  
 $Q^2 = -q^2 = -(k - k')^2$
- ▶ **Inelasticity:**  
 $y = Pq / Pk$
- ▶ **Boson-proton center of mass energy:**  
 $W = (q + P)^2 \approx y s - Q^2$

# QCD Models

	Rapgap 3.1	Cascade 1.2	HVQDIS
Type	LO+PS	LO+PS	FO NLO(massive)
Evolution	DGLAP	CCFM	DGLAP
Proton PDF	CTEQ5L	A0	CTEQ5F3
Photon PDF	SaS-G2D		
Scale	$Q^2+pt^2$	$4mc^2+pt^2$	$4mc^2+Q^2$
Mc	1.5	1.5	1.5
Fragmentation	Lund string	Lund string	Independent

## As implemented in Pythia 6.2

- ▶ **Default setting:** Pythia from the box (no  $D^{**} \rightarrow D^*X$ )
- ▶ **Aleph setting:** includes higher resonances (~27%  $D^*$  originating from  $D^{**} \rightarrow D^*X$ )

## "hand made" fragmentation

- ▶ c-quarks fragmented in  $\gamma p$  frame  $p_L(D^*)$  generated according to given parametrization ( $D^*$  put on mass shell)



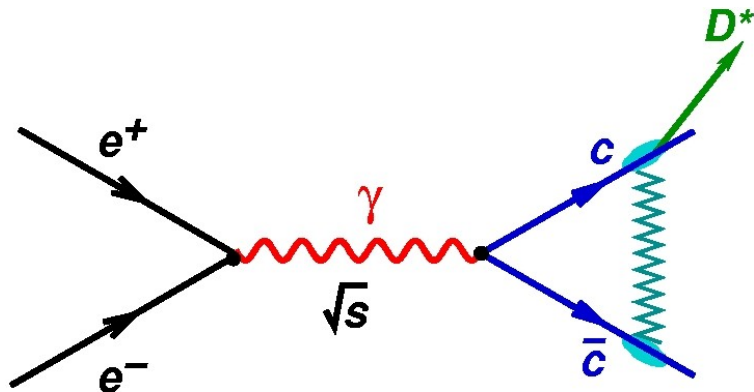
# Choice of Fragmentation Observable

## $e^+e^-$ collisions

- ▶ natural choice:

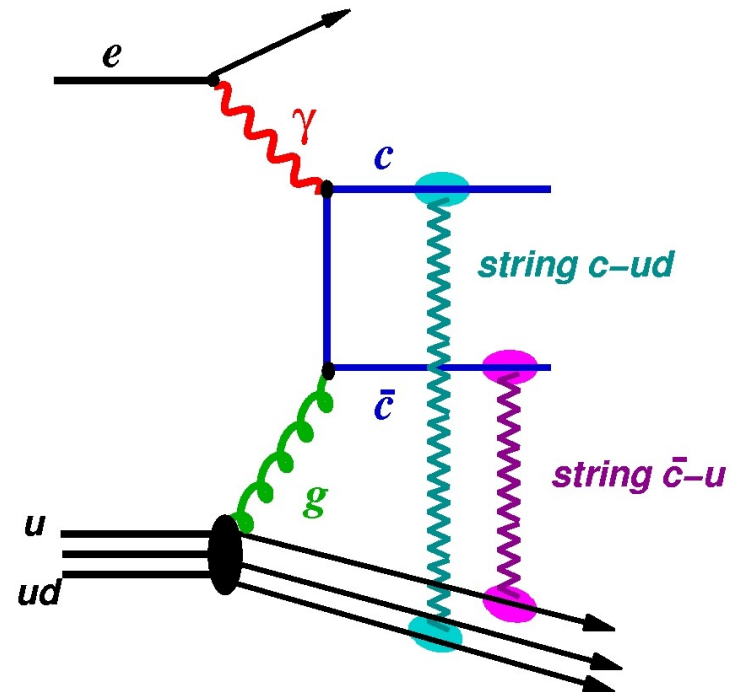
$$z = E_{D^*} / (1/2 \sqrt{s}) = E_{D^*} / E_{\text{BEAM}}$$

- ▶ in LO approximation  $E_{\text{BEAM}} = E_c$   
 $\Rightarrow z$  corresponds to direct measurement of FF



## $ep$ collisions

- ▶  $\sqrt{s}$  of hard subprocess unknown  
 $\Rightarrow$  choice of observable not obvious
- ▶ differences: presence of IPS  
 different color flow



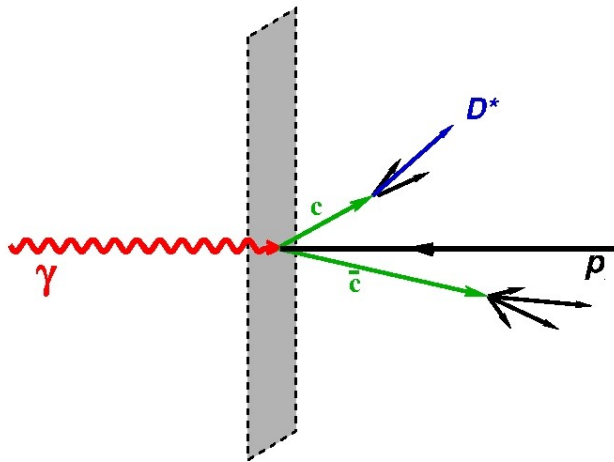
# Definitions of Observables

## Jet method:

- ▷ momentum of  $c$ -quark approximated by momentum of rec.  $D^*$ -jet

$$z_{\text{jet}} = \frac{(E+p_L)_{D^*}}{(E+p)_{\text{jet}}}$$

- ▷  $k_{\perp}$ -clus jet algorithm applied in  $\gamma p$ -frame ( $E_t(D^* \text{ jet}) > 3 \text{ GeV}$ )

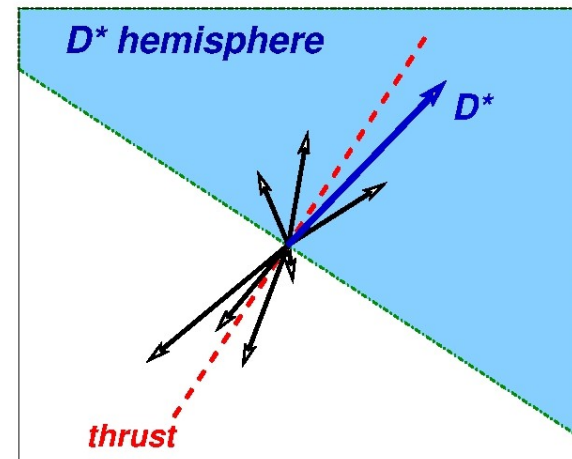


## Hemisphere method:

- ▷ momentum of  $c$ -quark approximated by momentum of rec.  $D^*$ -hemisphere

$$z_{\text{hem}} = \frac{(E+p_L)_{D^*}}{\sum_{\text{hem}} (E+p)_i}$$

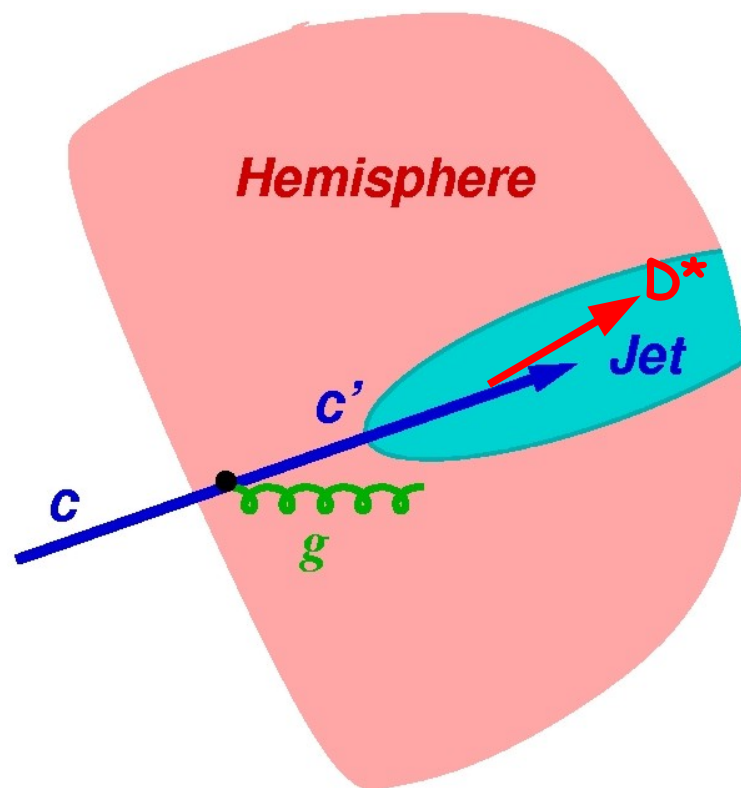
- ▷  $\eta(\text{part}) > 0$  for  $p$ -remnant suppression
- ▷ thrust axis in plane perpendicular to  $\gamma$  used for hemisphere division



# Comparison of Observables

## Hemisphere Method:

- ▶ Sums more gluon radiation than jet method



Interesting to measure both  $d\sigma/z_{hem}$  and  $d\sigma/z_{jet}$  because:

- ▶ Allows to test understanding of parton radiation
- ▶ Both distributions should look differently, but extracted non-pert. FF should be the same if model is perfect



# D\* Selection

Golden channel:  $D^* \rightarrow D^0 \pi_s \rightarrow K \pi \pi_s$

► DIS cuts:

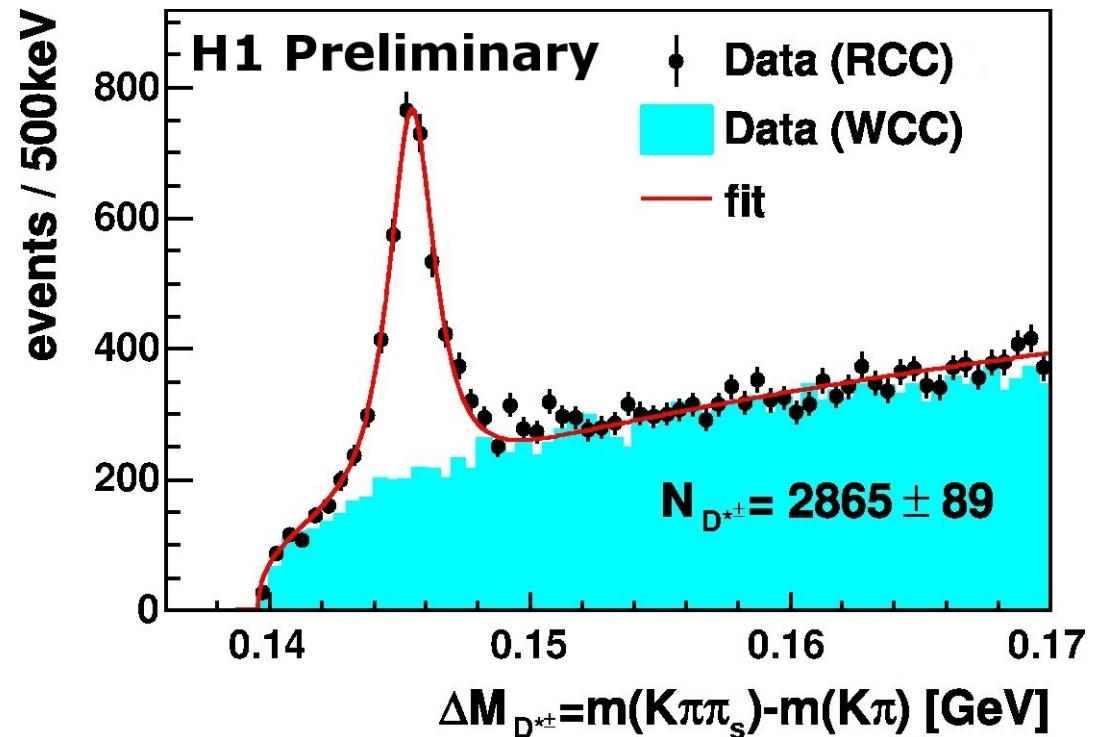
$$2 < Q^2 < 100 \text{ GeV}^2$$
$$0.05 < y_e < 0.7$$

► D\* cuts:

$$|\eta(D^*)| < 1.5$$
$$1.5 < P_T(D^*) < 15 \text{ GeV}$$
$$E_T(D^* \text{jet}) > 3 \text{ GeV}$$

► after  $E_T$  jet cut

$$N(D^*) \approx 1500$$



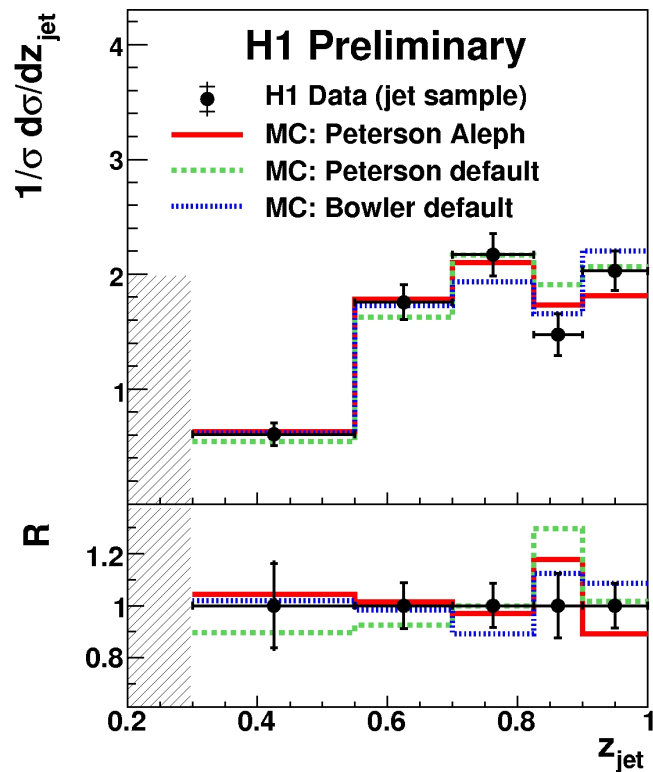
# Correction Procedure

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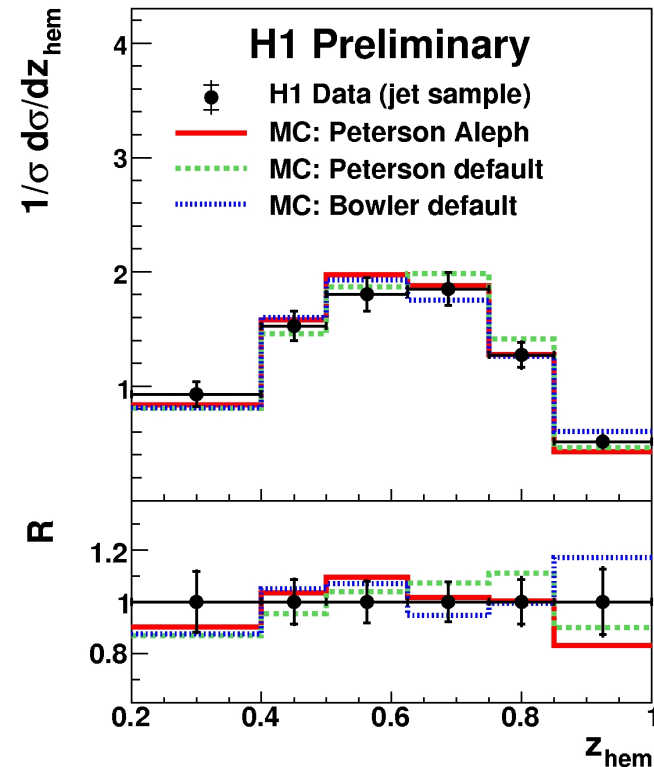
- ▶ **Subtraction of beauty component**
  - using bb RAPGAP MC prediction (fraction below 2%)
- ▶ **Correcting for detector effects**
  - **regularized unfolding procedure applied**, migrations from one bin into another one taken into account by detector response matrix
- ▶ **QED radiative corrections**
  - calculated by RAPGAP/HERACLES

# Frag. Observable Distributions

## Jet method



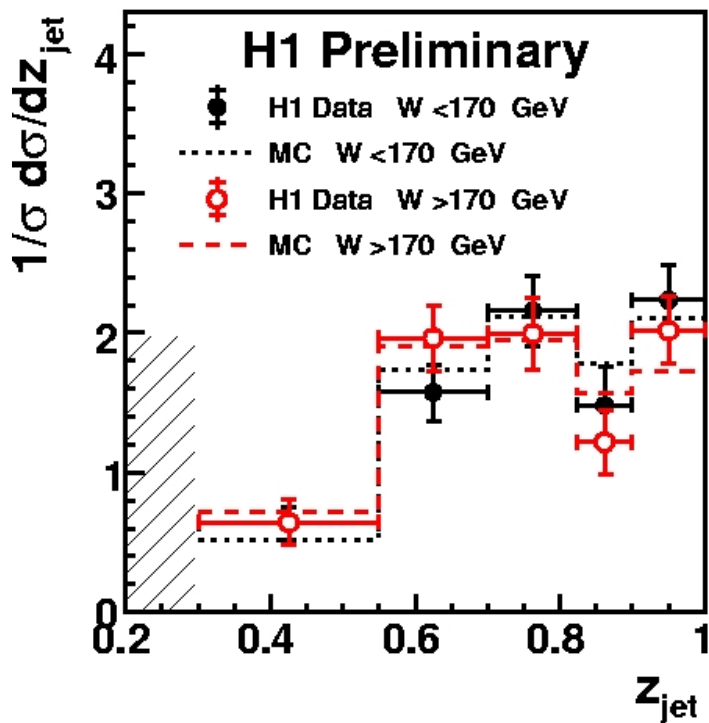
## Hemisphere method



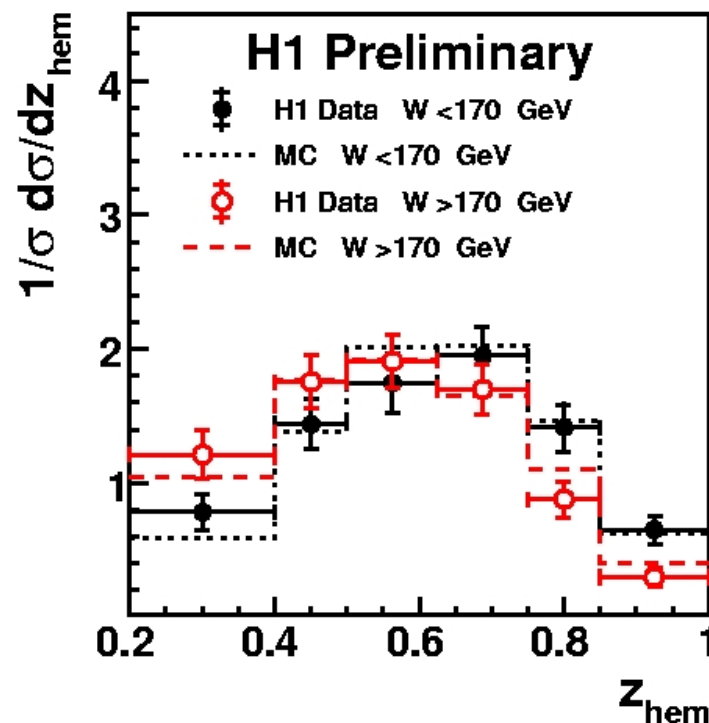
- ▶ observables compared with different MC fragmentation tunes (Rapgap/Pythia):
  - ▶ **Default:** Pythia out of the box, no higher resonances present ( $c \rightarrow D^*$ ),  $\epsilon=0.05$
  - ▶ **Aleph tune:** contains  $\sim 27\%$  of higher resonances ( $c \rightarrow D^*$ ,  $c \rightarrow D^{**} \rightarrow D^*$ ),  $\epsilon=0.04$
- ▶ **Good agreement found**

# Observables as Function of $W$

Jet method



Hemisphere method



►  $z$  as function of  $\gamma p$  cms energy  $-W$

► MC follows the trend in data

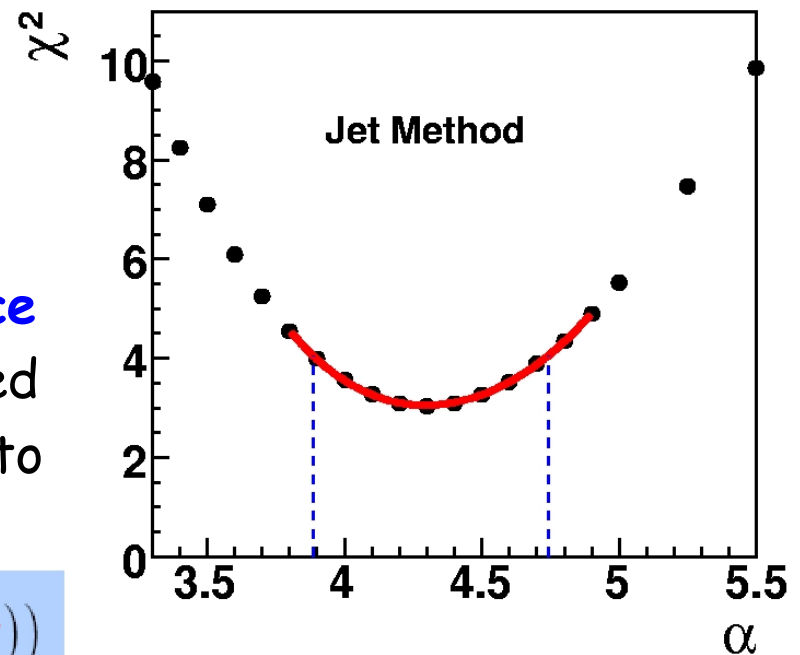
►  $z_{\text{hem}}$  includes more gluon radiation than  $z_{\text{jet}}$   $\rightarrow$  scale dependence more pronounced

# FF Extraction Procedure

Non-pert. Frag. function defined only within given theoretical model:

- ▶ **LO+PS Monte Carlo models** **RAPGAP** and **CASCADE** with Lund string fragmentation model as implemented in PYTHIA (default setting, Aleph setting)
- ▶ **NLO calculations** (HVQDIS)
- ▶ **Fitted parametrizations of non-pert. FF:** Kartvelishvili, Peterson
- ▶ **optimal parameters and confidence limits obtained from  $\chi^2$**  (correlated statistical and sys. errors taken into account)

$$\chi^2(\boldsymbol{\varepsilon}) = (\mathbf{z} - \mathbf{z}^{\text{MC}}(\boldsymbol{\varepsilon}))^T \mathbf{V}^{-1} (\mathbf{z} - \mathbf{z}^{\text{MC}}(\boldsymbol{\varepsilon}))$$

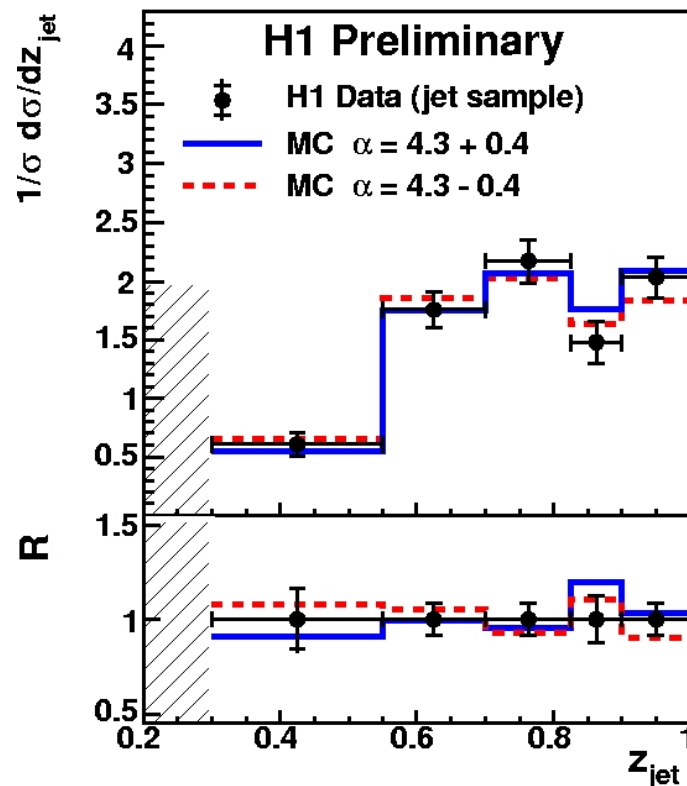


# Extracted FF Plots - MC

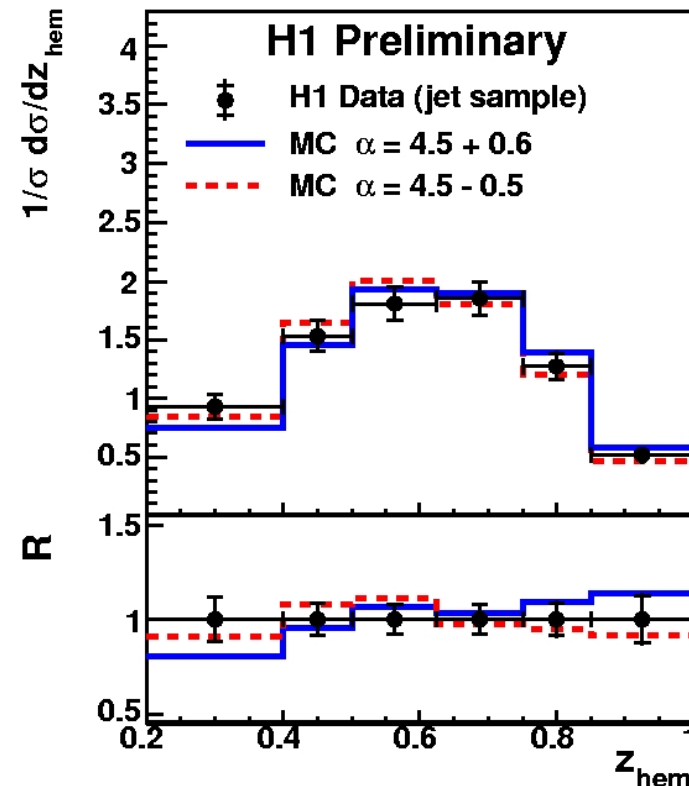
Rapgap with Aleph setting & Kartvelishvili parametrization:

(best fit  $\pm 1\sigma$  error shown)

**Jet method**



**Hemisphere method**



► both methods agree well with each other within errors



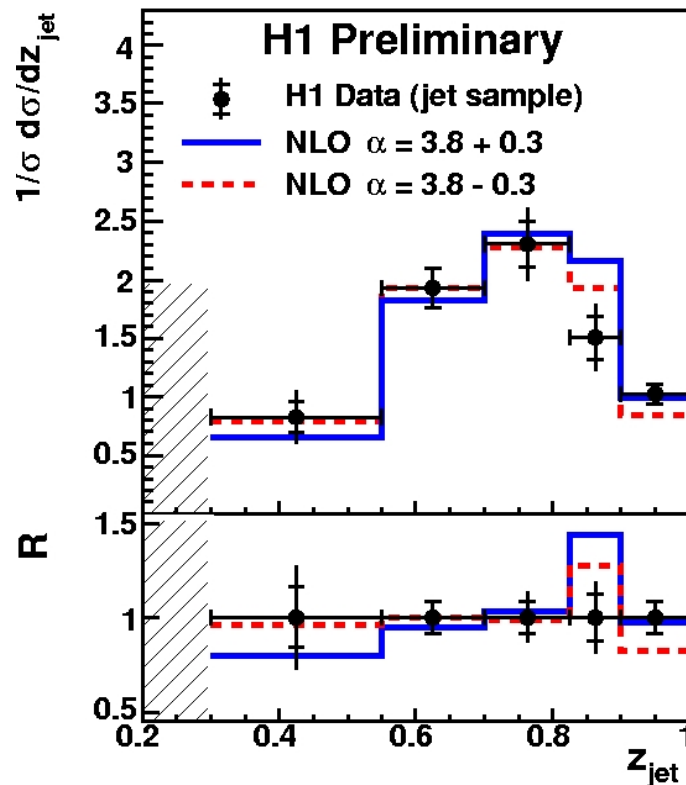
# Extracted FF Plots - NLO

## HVQDIS: massive NLO calculation

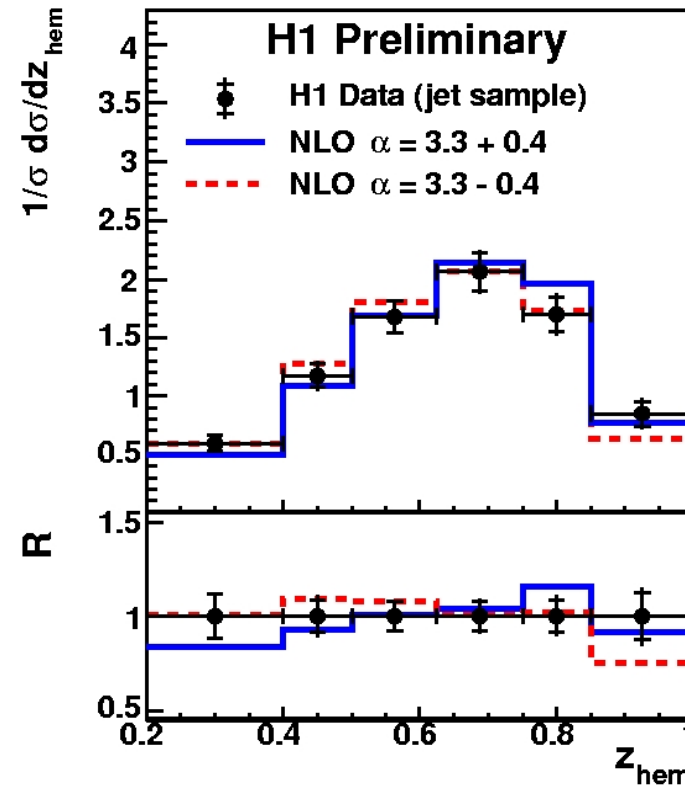
( $m_c = 1.5 \text{ GeV}$ ,  $\mu_r = \mu_f = \sqrt{Q^2 + 4m_c^2}$ , proton PDF = CTEQ5F3)

- ▶ **data corrected to parton level** & compared with NLO partonic cross-sections (c-quark fragmented independently in  $\gamma^*p$ -rest frame)

### Jet method



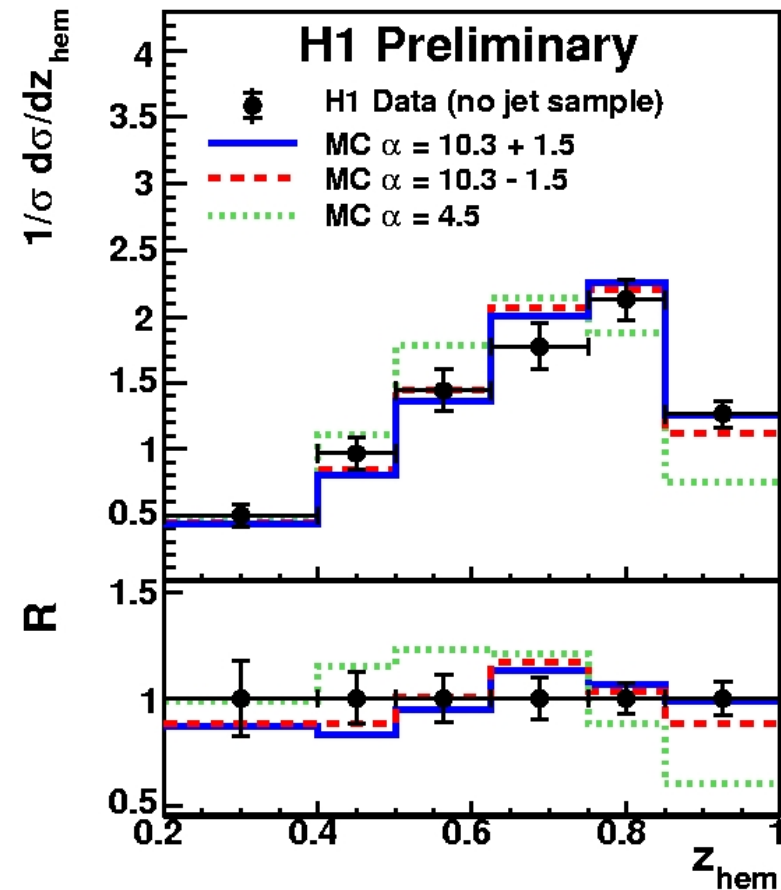
### Hemisphere method



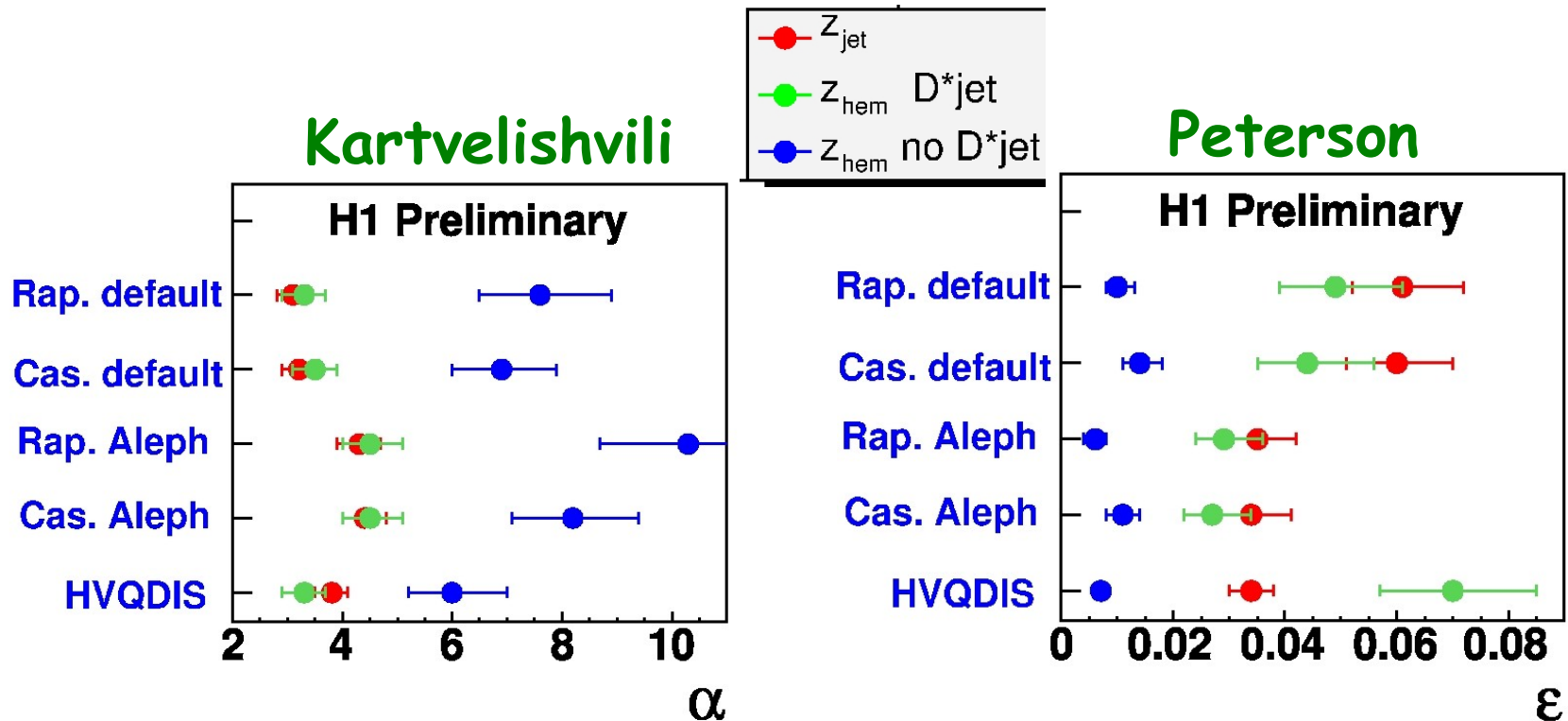
# Investigating the Threshold Region

- ▶ events not fulfilling hard scale cut  $E_T(D^*jet) > 3\text{GeV}$  (roughly 1300  $D^*$  events) ==> hemisphere method has to be used
- ▶ extracted FF almost  $4\sigma$  far from the FF extracted from the nominal sample (spectrum much harder!)
- ▶ discrepancy due to improper description of underlying physics close to the charm production threshold in QCD models
- ▶ NLO (HVQDIS) completely fails to describe the data ( $\chi^2_{\text{MIN}}/N_{\text{df}} \approx 40/4$ )

Rapgap with Aleph tune and Kartvelishvili FF:



# FF Parameter Fit Results (Summary)



- ▶ extracted Peterson parameter values in agreement with the  $\epsilon$  parameter in the Aleph tuned steering ( $\epsilon=0.04$ )
  - > **Confirms charm fragmentation universality between  $e^+e^-$  and  $ep$ , if hard scale is involved !**
- ▶ Peterson and Kartvelishvili parametrizations describe the data well, only in case of NLO Peterson strongly disfavored ( $\chi^2_{MIN}/N_{df} \approx 8$ )

# Conclusions I

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- ▶ **charm fragmentation studied with ep data at H1 experiment:**
  - ▶ two different observable definitions  $z_{\text{jet}}$  &  $z_{\text{hem}}$  used
  - ▶ reasonable description of data by QCD models found
- ▶ **FF parameters extracted for LO+PS MC models and NLO, using Peterson and Kartvelishvili parametrizations:**
  - ▶ both FF observables lead to consistent parameter values
  - ▶ ep FF parameters consistent with  $e^+e^-$  FF parameters  
--> **FF universality!**
- ▶ **Investigating threshold region with  $z_{\text{hem}}$ :**
  - ▶ poor description of data by MC
  - ▶ NLO (HVQDIS) fails completely
- ▶ **We don't understand charm physics over the full phase space**

# Conclusions II

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- ▶ Understanding of charm fragmentation is crucial for high precision measurements at HERA

**More theory input needed!**